An approach to estimation of sustainable catch limits for orange roughy in the SPRFMO Area

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1. Introduction

Bottom Fishery Interim Measures adopted by participants in the negotiations to establish the South Pacific Regional Fisheries Management Organisation (SPRFMO) require participants to:

> *Paragraph 1. 'Limit bottom fishing effort or catch in the Area to existing levels in terms of the number of fishing vessels and other parameters that reflect the level of catch, fishing effort, and fishing capacity.'; and*
>
> *Paragraph 6. Establish conservation and management measures to ensure the long-term sustainability of deep sea fish stocks*

New Zealand has chosen to give effect to these requirements through the setting of catch limits, initially focussing on the main bottom trawl target species, orange roughy (ORH), which contributes over 90% of the New Zealand high seas bottom trawl catch in the SPRFMO Area (Ministry of Fisheries 2008). However, determination of sustainable catch limits for orange roughy is difficult. There are substantial problems associated with acoustic surveys as a result of their low acoustic target strength and the depth (500m - 1500m) in which they are fished. Small quantities of other species with higher acoustic target strength mixed in with orange roughy shoals can dominate the acoustic return signal, making comprehensive and accurate target identification essential. A significant proportion of the biomass may also be lost in the seabed acoustic shadow and backscatter as a result of the transducer beam width at those depths, coupled with the low target strength.

As a result of the fact that most orange roughy catches are strongly targeted on accumulations and plumes on the sides or summits of seamount features, catch per unit effort (CPUE) is not considered to be a reliable indicator of overall abundance, particularly in the earlier stages of a fishery, when CPUE is more likely to reflect local availability of aggregations on targeted features. As a result of the great longevity of the species (matures at 23 - 31 years and can live to 120 - 130 years of age) and substantial uncertainty regarding stock-recruit relationships and frequency of spawning, stock assessments also tend to be unreliable, being driven predominantly by assumptions made regarding current and future recruitment rates. Estimation of orange roughy biomass is particularly challenging on the high seas where no fishery independent acoustic or trawl surveys have been conducted to provide abundance indices.

To provide a range of information which could be used to estimate sustainable catch limits for orange roughy in the high seas fished areas, the New Zealand Ministry of Fisheries contracted a research project to analyse historical catch, effort and standardised CPUE trends; update predictive modelling estimates of ORH biomass on underwater topographic features; and develop estimates of sustainable catches for orange roughy fisheries within the New Zealand bottom trawl effort footprint in the SPRFMO area. The final research report for this project was completed in February 2010 and published by Clark *et al*. (2010, in press). This overview paper summarises the key results of that research, which currently constitute the best available scientific information to inform the setting of sustainable ORH catch limits for the fished trawl footprint regions of the SPRFMO Area.

2. Average Historical Catches

Catch and effort data for New Zealand bottom fisheries were extracted and groomed to provide information on historical bottom fishing catch and effort by New Zealand flagged vessels for the New Zealand SPRFMO bottom fishery impact assessment report (Ministry of Fisheries 2008).

Total reported New Zealand flag annual catches of orange roughy over the SPRFMO interim measures reference period (calendar years 2002 – 2006), and updated to include subsequent years, are summarised in Table 1 and shown in Figure 1 by fishing area. The average annual New Zealand orange roughy catch in all high seas fishing areas in the SPRFMO Area over the reference period 2002 – 2006 was 1,852 t.

Table 1. Total annual reported catches by New Zealand flagged fishing vessels by high seas fishing area from 2002 to 2007, and average annual catch per area over the SPRFMO Interim Measures reference period of 2002 – 2006 (updated from Ministry of Fisheries 2008).

Year	Challenger	West Norfolk	Lord Howe	Louisville N	Louisville C	Louisville S	Other	Total
2002	1,460	432	96	102	311	155	22	2,578
2003	868	25	218	440	90	329	3	1,973
2004	347	106	132	287	430	389	5	1,697
2005	425	327	190	123	253	247	33	1,597
2006	202	670	29	111	96	286	22	1,415
2007	36	515	34	1	77	202	0	866
2008	31	426	380					837
2009	292	233	403					928
2002-06 Average	660	312	133	212	236	281	17	**1,852**

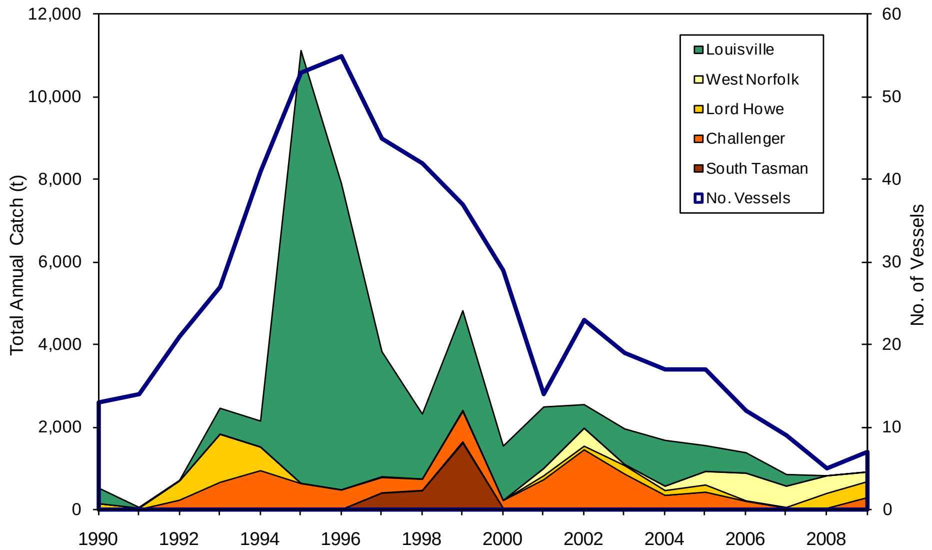

Figure 1. Total annual reported orange roughy catch (t) by New Zealand flagged vessels, and overall number of vessels, by fishing area over the period 1990 - 2009 (updated from MFish 2008).

3. Catch per Unit Effort Analyses

The work of Clark *et al*. (2010) focussed on analysis of two main information sources to develop estimates of sustainable orange roughy catch levels by fishing area: i) standardised CPUE analysis of high seas orange roughy catch and effort data; and ii) an update of the seamounts meta-analysis conducted by Clark *et al*. (2001) to provide statistical model estimates of original (unfished) orange roughy biomass on groups of underwater topographic features.

Regular fishery characterisations and unstandardised CPUE analyses have been conducted for New Zealand high seas orange roughy fisheries since 1998, the most recent being by Clark (2008). Under the project reported on here (Clark *et al*. 2010, in press), ORH CPUE data were updated and standardised CPUE analyses were conducted. ORH high seas catch and effort by 1/10th of a degree latitude and longitude shows a sequential progression of effort, catch and CPUE to new areas over time. This is particularly evident in trends in geographic progression in CPUE from 1990 onwards (Figure 2). Although there continues to be a fairly wide spread of fishing effort, catches have typically declined rapidly on individual features, and CPUE has seldom been maintained in a particular 0.1° square for more than a year or two since 1990. A strong trend of sequential movement to new fishing areas (0.1° squares) is particularly evident from 1995 – 2005, with an associated trend of sequential depletion, with high catch rates seldom being maintained in any particular 0.1° square for more than two years over this period (Figure 2).

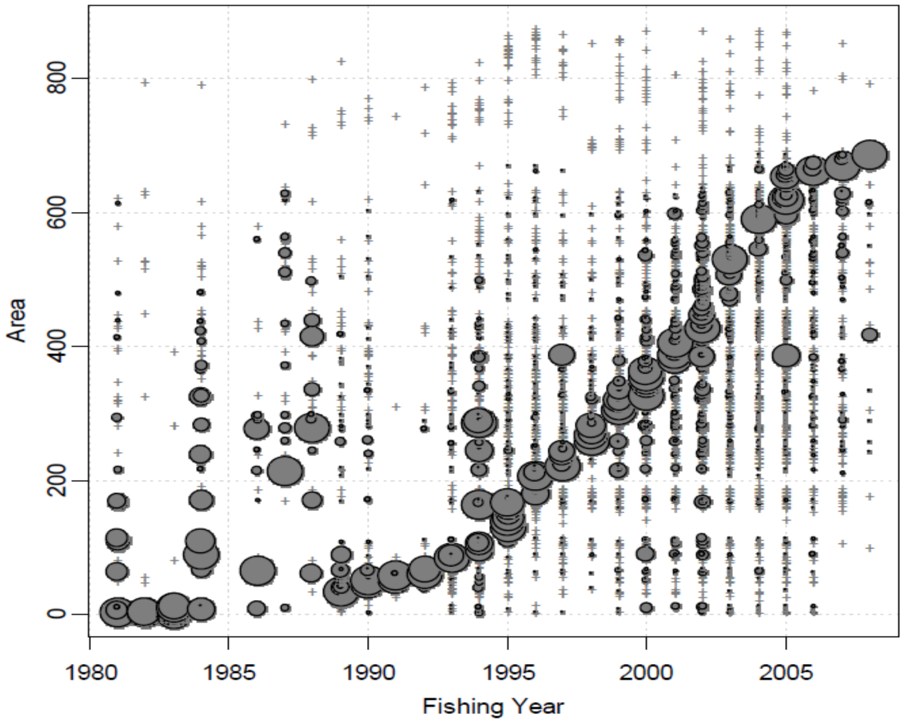

Figure 2. The distribution of orange roughy unstandardised median catch rate (t/tow) by fishing year and area (where area is a square of 1/10th of a degree latitude and longitude) for the total high seas fishery. Catch rates are proportional to circle size; each year sums to 1. Crosses indicate areas where effort took place but no catch was taken. Fished 1° squares have been ordered by mean year in which the catch was taken. (Clark *et al*. 2010)

Analysis of sequential progression of ORH CPUE by 0.1° square by individual fishing area (Figure 3) shows that this sequential progression has occurred in most fishing areas, but to a greater or lesser extent over different time periods. Looking at the individual fishing areas:

- In the longest fished area, the NW Challenger Plateau, there is less evidence of a sequential shift to new areas than of a steady expansion in fished area. Over 1992 – 1999, successful fishing remained much in the same few areas fished at the start of this fishery. Between 1999 and 2003 there was then a rapid expansion of the fishery, rather than a shift away from old areas, with increasing numbers of areas fished each year. Only in 2006 was there then a drop-off in CPUE in the early fished areas, and an emphasis on the most recently fished areas.

- Along the Louisville Ridge, progressive movement to new fishing areas is particularly evident in all areas in earlier years (1994 – 2000 or 2002), but not in later years. Since about 2002, fishing on the Louisville Ridge has tended to remain in the areas fished towards the end of the 1994 – 2002 period, with less evidence of recent, ongoing sequential progression.
- The opposite has happened in the Lord Howe Rise area. From 1994 – 2000, fishing tended to occur on much the same areas throughout the period. However, from 2000 onwards there has been a fairly steady progression (except 2003) to new areas, with a move to new areas being particularly evident over 2002 – 2006.
- The most recently fished area, the West Norfolk Ridge, has only been fished since 2001, and shows a strong progression to new areas each year, with very few areas being successfully fished for more than one or two years.

With regard to interpreting CPUE trends for these fishing areas, it is important to note that any steady progression away from old areas and into new areas will upwardly bias, and result in strong hyper-stability, of overall CPUE. Under such conditions, stable CPUE trends may mask declines in the overall population resulting from sequential depletion of aggregations on particular features.

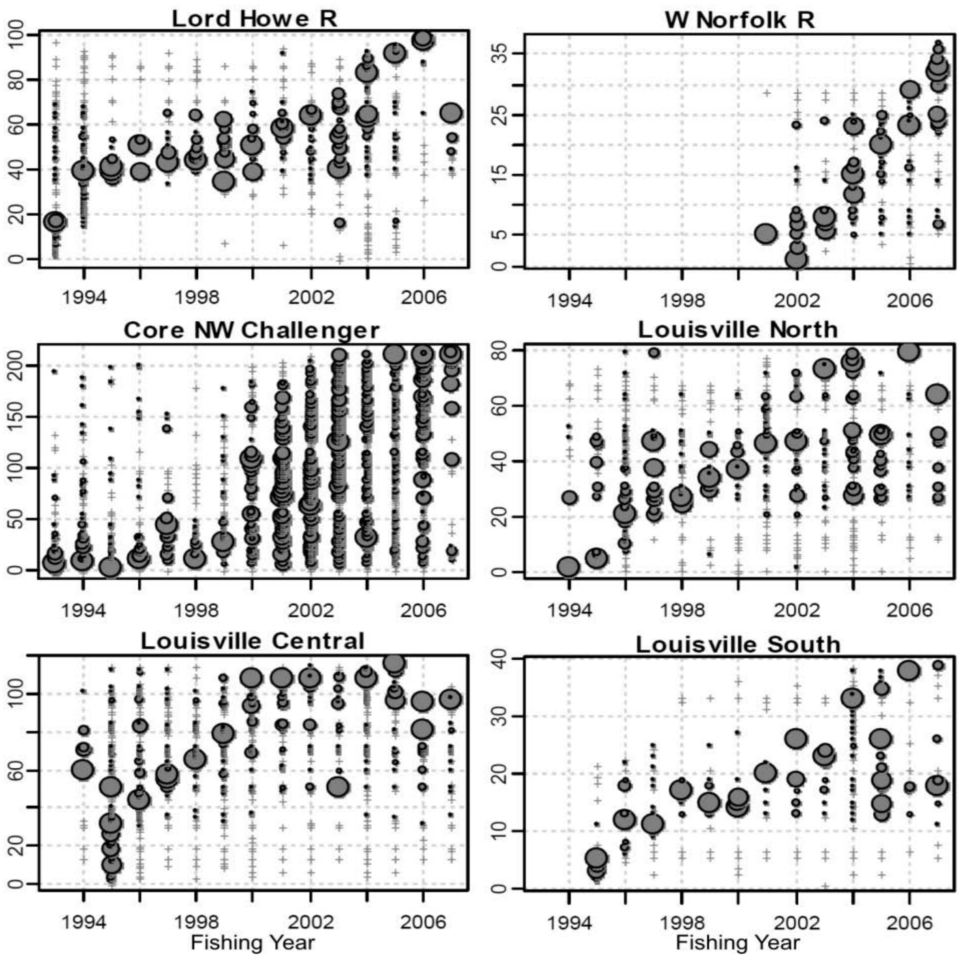

Figure 3. The distribution of orange roughy unstandardised median catch rate (t/tow) by fishing year and area (where area is a square of 1/10th of a degree latitude and longitude) for subareas of the high seas fishery. Catch rates are proportional to circle size; each year sums to 1. Crosses indicate areas where effort took place but no catch was taken. Areas were ordered by mean year in which the catch was taken. (Clark *et al*. 2010)

The standardised CPUE trends from Clark *et al*. 2010 for these fishing areas are shown in Figure 4.

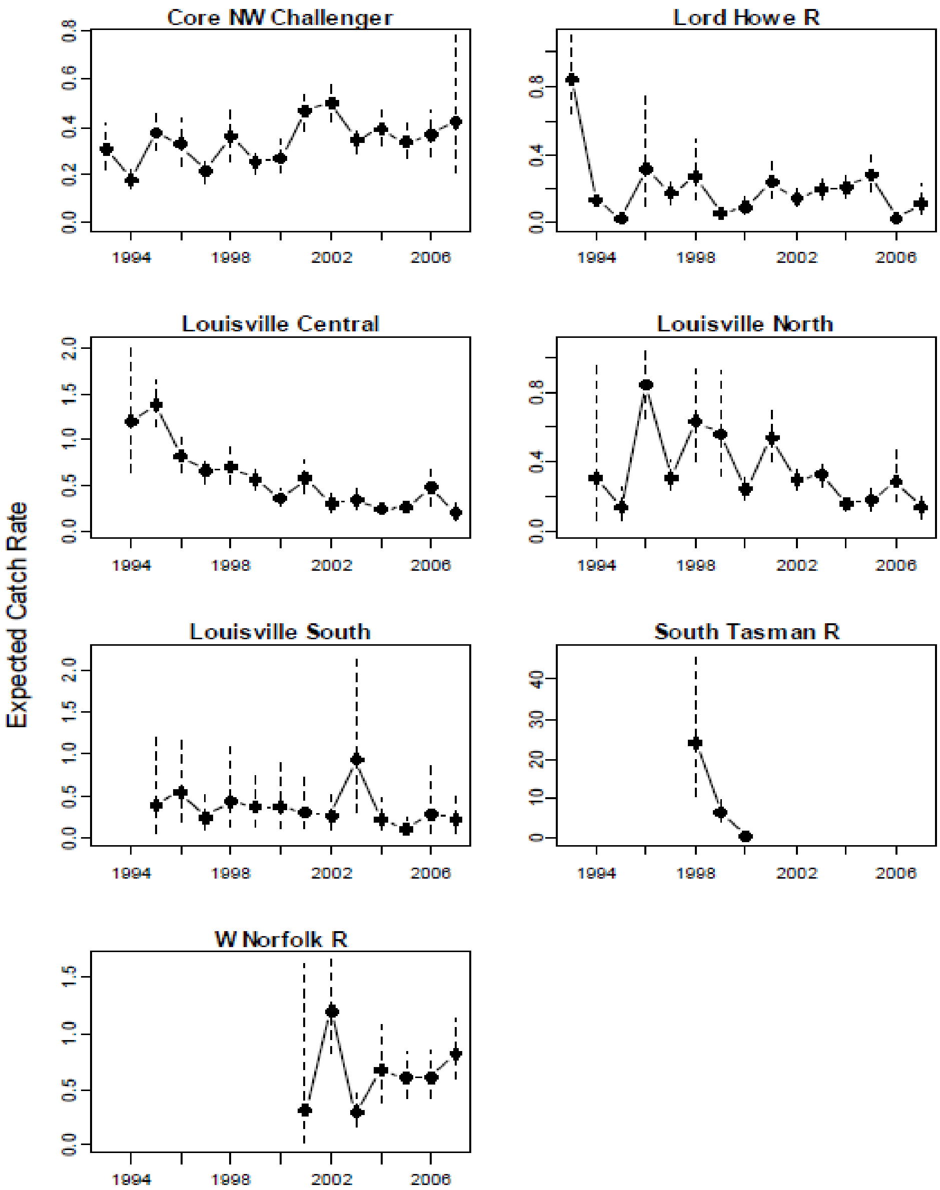

Figure 4. Standardised CPUE trends (model prediction fishing year effects) for orange roughy by fishing area outside of the EEZ, made with all other predictors set to the median (fixed) values. (Clark *et al*. 2010)

4. Seamount Meta-Analyses

Meta-analysis and predictive modelling has been developed by Clark *et al*. (2001) as a method for estimating original (unfished) orange roughy biomass on seamounts and underwater topographic features. This approach was updated under IFA 2008-05 to extend results of this analysis (originally confined to predicting ORH biomass on features within the NZ EEZ) to the high seas.

The methods and detailed results are described in Clark *et al*. (2010) who present two sets of results: one for all seamount features in the fishing areas, and one excluding seamounts at the extreme northern and southern extents of the trawl footprint. As noted by the authors, absence of orange roughy trawl catches at the northern (northern West Norfolk Ridge) and southern (southern

Louisville Ridge) extremes of the fishing areas indicates that seamounts at these extremes do not appear to support significant quantities of orange roughy and should be excluded from the analysis. Biomass estimates generated by the meta-analysis for each fishing area after exclusion of these peripheral seamounts are summarised in Table 2, together with corresponding estimates of maximum constant yield (MCY) and maximum annual yield (MAY) by fishing areas (see Appendix A for an explanation of the MCY and MAY catch reference levels).

Table 2. Comparison of predicted original (unfished) biomass by fishing area from seamounts meta-analysis (adjusted to exclude edge-of-range seamounts that have not produced ORH catches), total reported orange roughy catch for each area, and estimated yields per region (MCY – maximum constant yield; MAY – maximum annual yield) based on the adjusted biomass values.

Fishing Area	Number of Seamounts	Predicted Biomass (t)	Reported Catch (t)	MCY (t)	MAY (t)
West Norfolk	10	5,350	1,838	80	110
Lord Howe	3	4,130	786	60	80
NW Challenger	14	8,800	4,646	130	170
North Louisville	11	7,510	8,214	110	150
Central Louisville	10	38,620	20,307	580	770
South Louisville	6	5,200	5,176	80	100

5. Summary of Available Information on Sustainable Catch Levels

The obligation to evaluate whether high seas fishing activities will have significant adverse impacts on the long-term sustainability of deep sea fish stocks dates back to paragraph 83(b) of UN General Assembly Resolution 61/105 (2007). Specific guidelines for implementation of precautionary measures to ensure sustainability of low productivity species were included in the FAO International Guidelines for the Management of Deep-Sea Fisheries on the High Seas (FAO 2009):

> *65. Precautionary conservation and management measures, including catch and effort controls, are essential during the exploratory phase of a DSF, and should be a major component of the management of an established DSF. They should include measures to manage the impact of the fishery on low-productivity species, non-target species and sensitive habitat features. Implementation of a precautionary approach to sustainable exploitation of DSFs should include the following measures:*
>
> > *i. precautionary effort limits, particularly where reliable assessments of sustainable exploitation rates of target and main bycatch species are not available;*
> >
> > *ii. precautionary measures, including precautionary spatial catch limits where appropriate, to prevent serial depletion of low productivity stocks;*
> >
> > *iii. regular review of appropriate indices of stock status and revision downwards of the limits listed above when significant declines are detected;*

The FAO guidelines go on to provide advice on the maximum levels of fishing mortality which should be established for low productivity species:

> *77. In general, for low-productivity species, fishing mortality should not exceed the estimated or inferred natural mortality. Sustainable management strategies that would be robust to uncertainties are likely to require low exploitation rates.*

Provided an estimate is available of the natural mortality rate (M) of a species, and where estimates of unexploited biomass level (B_0) are available, sustainable catch levels compliant with the FAO guidelines can be proposed by adopting a management approach of setting $F = M$, and determining catch limits by multiplying this *F* by the best estimate of B_{MSY} to establish catch limits at estimated maximum sustainable yield (*MSY*) levels.

Information on predicted biomass, estimated *MCY* and *MAY* (from Clark *et al*. 2010) and average annual catches over the SPRFMO Interim measures reference period (2002-06) are summarised for each fishing area in Table 3. Gulland (1971) then provides a method for estimating *MSY* from estimates of natural mortality (*M*) and unexploited biomass (B_0):

$$MSY = \frac{1}{2} M B_0$$

The current best estimate of natural mortality (*M*) for orange roughy is 0.045 (MFish 2010) and Table 3 includes estimates of *MSY* for each fishing area calculated using the above formula.

Table 3. Summary of predicted biomass (from the seamounts meta-analysis excluding seamounts at the extreme northern and southern ranges), estimated MCY and MAY (from predicted biomass), estimated MSY (½MB_0) and average (raised) annual orange roughy catches over the SPRFMO 5 year reference period (2002-06) by fishing area.

Fishing Area	Predicted Biomass (t)	MCY	MAY	½MB_0	2002-06 Average
Lord Howe	4,130	60	80	93	134
West Norfolk	5,350	80	100	120	315
NW Challenger	8,800	130	170	198	666
North Louisville	7,510	110	150	169	214
Central Louisville	38,620	580	770	869	238
South Louisville	5,200	80	100	117	284
Total	69,610	1,040	1,380	1,566	1,852

Trends in annual catch (t) (updated from Ministry of Fisheries 2008) and standardised CPUE (t/tow) (from Clark *et al*. 2010) from 1990 to 2009 are shown for each fishing area in Figure 5, plotted against reference lines for catch levels at MCY, MAY, ½MB_0 and the 2002-06 average annual catch (from Table 3).

6. Potential Sustainable Catch Limits by Area

If SPRFMO Interim measures are to be implemented in the form of a catch limit then, in terms of SPRFMO bottom fishing interim measure 1, the total New Zealand SPRFMO Area orange roughy catch limit should not exceed the average annual catch over the 2002-06 reference period of 1,852t. Results from Clark *et al*. (2010) summarised above suggest that long-term sustainable catch levels may well be below the average annual catches over 2002-2006, particularly in some fishing areas. Information relevant to establishing area-based sustainable catch limits is summarised below for each fishing area, including: CPUE (from Figures 3 and 4); estimated biomass, MCY, MAY and ½MB_0 reference levels and 2002-06 average catches (from Table 3).

Lord Howe Rise

Fishing on the Lord Howe Rise shows a regular progression to new fishing areas in most years since about 2001. Since 1994, standardised CPUE in this area has fluctuated without trend. The steady progression to new areas is likely contributing to hyper-stability in CPUE, and/or biasing CPUE upwards. Biomass in this area is estimated to be the lowest of all fishing areas, with estimates of MCY and MAY of < 100t. Catches exceeded this level over 2001 to 2005, but remained below that level over 1995 to 2000 and 2005 to 2008. Catches increased significantly again in 2009 to exceed 2002 - 2006 average levels.

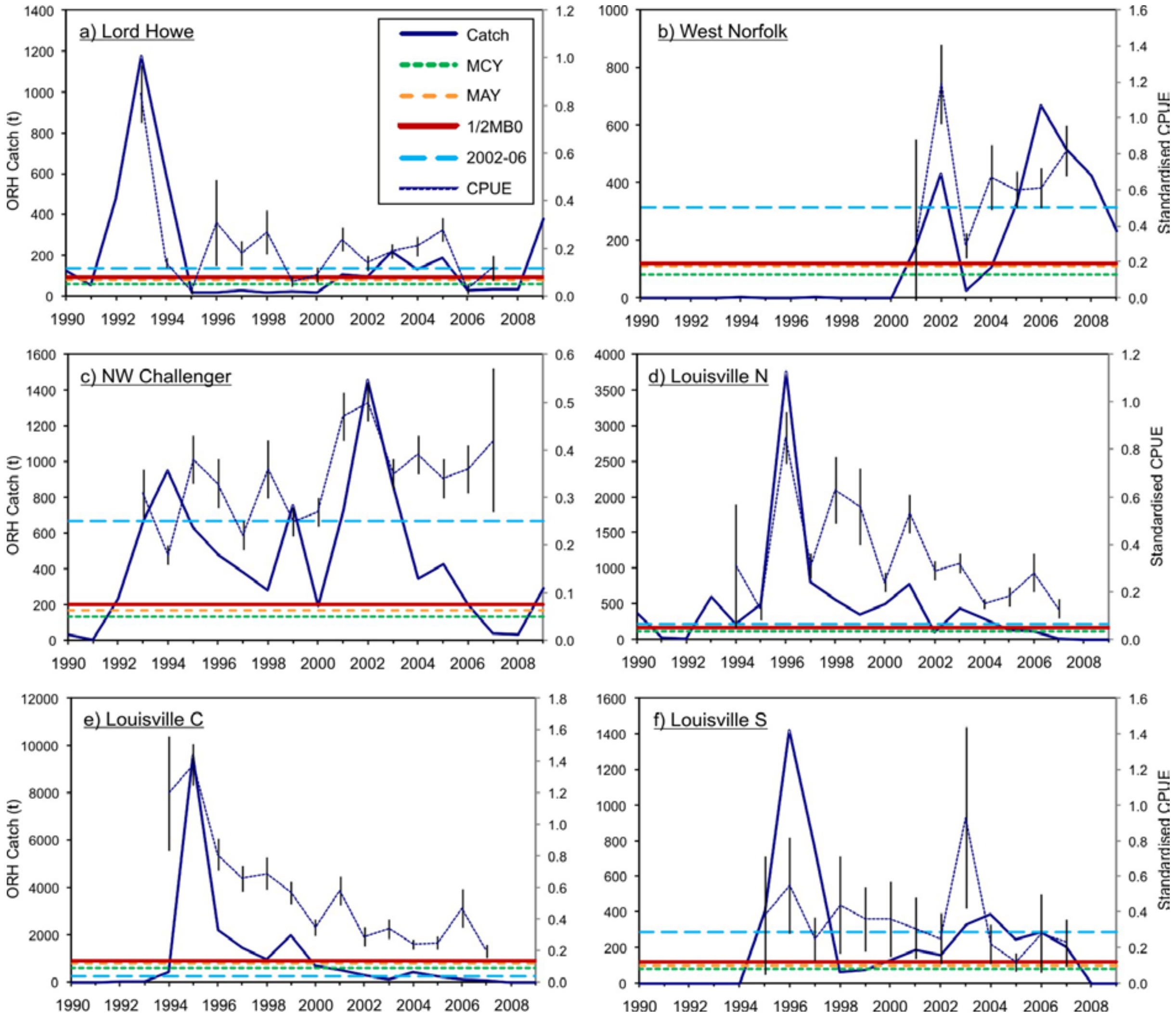

Figure 5. Summary of annual trends in total orange roughy catch (t), CPUE (t/tow, with standard errors) and estimated MCY, MAY, ½MB_0 and 2002-2006 average catch reference levels for the fishing areas a) Lord Howe Rise, b) West Norfolk Ridge, c) Northwest Challenger Plateau, d) North Louisville Ridge, e) Central Louisville Ridge and f) South Louisville Ridge.

West Norfolk Ridge

Fishing on the West Norfolk Ridge shows a strong annual progression to new fishing areas ever since the fishery commenced in 2001. Standardised CPUE fluctuated sharply in the early (exploratory?) three years of this fishery, but has been stable or slowly increasing since 2004. The strong progression to new areas is highly likely contributing to hyper-stability in CPUE, and/or biasing CPUE upwards. Predicted biomass in this area (excluding seamounts which have not produced orange roughy catches) is only moderately higher than the Lord Howe area, with estimated MAY of just over 100 t. This is a developing fishery and catches have increased rapidly since 2003. Current catches substantially exceed estimated MCY, MAY and ½MB_0 (although declined somewhat below 2002 - 2006 average levels in 2009, apparently as effort shifted back to the NW Challenger and Lord Howe Rise areas). This fishery is therefore likely to be in a fishing-down phase.

Northwest Challenger Plateau

There was a rapid expansion in areas fished on the NW Challenger from relatively few areas prior to 1999, to catch and effort covering most of the area since then. Standardised CPUE is estimated to have been increasing slowly but steadily in this area throughout the series. Substantial expansion of the fishing area after 2000 may have contributed to this increasing CPUE. However, fishing remained widespread from 2002 – 2006, only contracting to recently fished areas in 2007. Change in fishing areas is likely to have had less effect (in terms of hyper-stability and upwards bias) on CPUE in this area. Biomass on the NW Challenger is estimated to be second highest of the areas, exceeded only by the central Louisville, with MCY / MAY estimated to be between about 150 – 200t. The 2002 – 2006 average catch levels exceed MCY, MAY and ½MB_0 but declined sharply from 2002 through to 2008 as effort shifted to new fishing areas like the West Norfolk Ridge. Catches increased again in 2009 to exceed the MCY, MAY and ½MB_0 reference levels, being contributed to by a trawl survey conducted by industry in that year.

Louisville Ridge

All areas of the Louisville Ridge (Northern, Central and Southern) showed a progression of fishing areas from 1994 to about 2001, with fishing effort tending to remain on similar areas thereafter. Standardised CPUE has shown a fairly steady decline in most Louisville Ridge fishing areas since 1995 or 1996, particularly in the most heavily fished central Louisville. The combination of stable fishing areas and declining CPUE in recent years suggest that CPUE may be indexing a decline in local abundance or availability in these fished areas over the past 5 to 10 years. Biomass estimates on the Louisville Ridge are moderate to high, the estimate for the central Louisville exceeding the combined total for all other fishing areas. While MCY / MAY estimates for the northern and southern Louisville are between about 100 – 150 t, those for the central Louisville are between about 600 – 800 t.

Recent catch trends differ between the three Louisville Ridge areas. In the historically most heavily fished northern and central areas, after the sharp decline in catches from 1995-96 to 1996-97, catches continued to show a steady decline, reaching lowest levels in recent years, with no at all fishing in 2008 or 2009. This is probably partially a result of historical declines in CPUE and a reduced interest in fishing in these distant areas, with a shift to fishing in closer areas such as the West Norfolk Ridge instead. In these two areas, catches since 2004 have been below MCY / MAY levels, particularly in the central Louisville. In contrast, catches generally increased through to 2004 on the southern Louisville following the low catch in 1998, and then declined again to 2007, with no fishing in 2008-2009. Catches over 2003 – 2007 were at about the 2002 - 2006 average, at more than double the estimated MCY and MAY levels.

7. Conclusions

In the absence of representative abundance indices (such as those which might be provided by wide-area fishery-independent acoustic or trawl surveys), there remains little choice but to use available information generated by fishing activities as a basis for estimation of sustainable catch limits for low productivity species such as orange roughy. Notwithstanding the many limitations of CPUE data for such fisheries, Clark *et al*. (2010) note that correlation between declines over time across many different features fished within the New Zealand EEZ does appear to be providing some consistent signal. It certainly seems likely that declining CPUE despite continual, sequential progression of fishing to new features or areas (such as shown in Figure 3, and which would be expected to bias catch rates upwards and result in hyper-stability of CPUE), does indicate declining overall abundance across the area in which those fished features occur.

It is unlikely that fishery independent surveys will be conducted of low-productivity, high-seas bottom fishery resources. It is therefore unlikely that any of the traditional acoustic or trawl survey abundance indices will become available for these resources. As is the case with evaluating the likelihood of presence of VMEs on the high-seas, use must therefore be made of predictive approaches to estimate the abundance of species such as orange roughy in these areas, based on modelled relationships between abundance, oceanography and topography on features which have been fished for long enough to provide an estimate of original standing stock. The seamounts meta-analysis conducted by Clark *et al*. (2001, 2010) is such a predictive approach.

Taking into account the different fishing histories in these fishing areas, and the likely difference in state of exploitation of the stocks in each area, the above analyses indicate that short-term (2 – 5 year) orange roughy fishing area catch limits could lie somewhere between the estimated *MCY / MAY / MSY* levels for each area, and recent average catches, ensuring that the combined total of the individual catch limits does not exceed the average annual total catch of 1,852 t over the 2002 – 2006 reference period (in order to comply with the requirements of the SPRFMO interim measures).

However, the 2002 - 2006 average catches exceed the estimated long-term sustainable yields (MCY, MAY or MSY) determined using predicted unfished biomass in each area for all areas except the Central Louisville Ridge (Table 3). It has also been established that Gulland's (1971) $\frac{1}{2}MB_0$ formula tends to over-estimate *MSY* (see for example Deriso 1982, Beddington & Cooke 1983, Garcia *et al*. 1989). Over the longer-term, sustainable catch limits should therefore probably be set at levels below $\frac{1}{2}MB_0$ (combined total of 1,566 t), at the estimated MCY (total 1,040 t) or MAY (total 1,380 t) levels for each fishing area.

8. References

Beddington, J. and J.G. Cooke (1983). The potential yield of fish stocks. *FAO Fish. Tech. Pap*., 242: 47 pp.

Clark, M.R., B. Bull, and D.M. Tracey (2001). The estimation of catch levels for new orange roughy fisheries on seamounts: a meta-analysis of seamount data. *New Zealand Fisheries Assessment Report 2001/75*, 40 pp.

Clark, M.R. (2008). Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, and Louisville Ridge to the end of the 2006−07 fishing year. *New Zealand Fisheries Assessment Report 2008/66*, 24 pp.

Clark, M.R., M. Dunn and O. Anderson (2010). Development of estimates of biomass and sustainable catches for orange roughy fisheries in the New Zealand region outside the EEZ: CPUE analyses, and application of the "seamount meta-analysis" approach. *New Zealand Fishery Assessment Report* (in press), 46 pp.

Deriso, R.P., 1982. Relationship of fishing mortality and growth and the level of maximum sustainable yield. *Can. J. Fish. Aquat. Sci.*, 39: 1054-1058.

Food and Agriculture Organization of the United Nations (FAO) (2009). International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. FAO, Rome, 73 pp.

Garcia, S., P. Sparre and J. Csirke (1989). Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. *Fisheries Research*, 8: 13 – 23.

Gulland, J.A. (1971) The fish resources of the Ocean. Publisher: Fishing News (for the Food and Agriculture Organization), West Byfleet, England, 255 pp.

Ministry of Fisheries (2008). Bottom Fishery Impact Assessment: Bottom Fishing Activities by New Zealand Vessels Fishing in the High Seas in the SPRFMO Area during 2008 and 2009. Risk and Impact Assessment Report submitted to SPRFMO, 107 pp.

Ministry of Fisheries (2010). Report from the Fisheries Assessment Plenary, June 2010: stock assessments and yield estimates.

Appendix A

New Zealand Ministry of Fisheries: Guide to Biological Reference Points

Definitions of ***MCY, CAY*** and ***MAY***

The Fisheries Act (1996) defines Total Allowable Catch in terms of maximum sustainable yield (***MSY***). The definitions of the biological reference points, ***MCY*** and ***CAY***, derive from two ways of viewing ***MSY***: a static interpretation and a dynamic interpretation. The former, associated with ***MCY***, is based on the idea of taking the same catch from the fishery year after year. The latter interpretation, from which ***CAY*** is derived, recognises that fish populations fluctuate in size from year to year (for environmental and biological, as well as fishery, reasons) so that to get the best yield from a fishery it is necessary to alter the catch every year. This leads to the idea of maximum average yield (***MAY***) which is how fisheries scientists generally interpret ***MSY*** (Ricker 1975). The definitions are:

- ***MCY*** – Maximum Constant Yield: The maximum constant catch that is estimated to be sustainable, with an acceptable level of risk, at all probable future levels of biomass.
- ***CAY*** – Current Annual Yield: The one-year catch calculated by applying a reference fishing mortality, F_{ref}, to an estimate of the fishable biomass present during the next fishing year. F_{ref} is the level of (instantaneous) fishing mortality that, if applied every year, would, within an acceptable level of risk, maximise the average catch from the fishery.
- ***MAY*** is then the long-term average annual catch when the catch each year is the ***CAY***.

MCY is generally less than ***MAY*** (Doubleday 1976, Sissenwine 1978, Mace 1988a) as ***CAY*** will be larger than ***MCY*** in the majority of years. However, when fishable biomass becomes low (through overfishing, poor environmental conditions, or a combination of both), ***CAY*** will be less than ***MCY***.

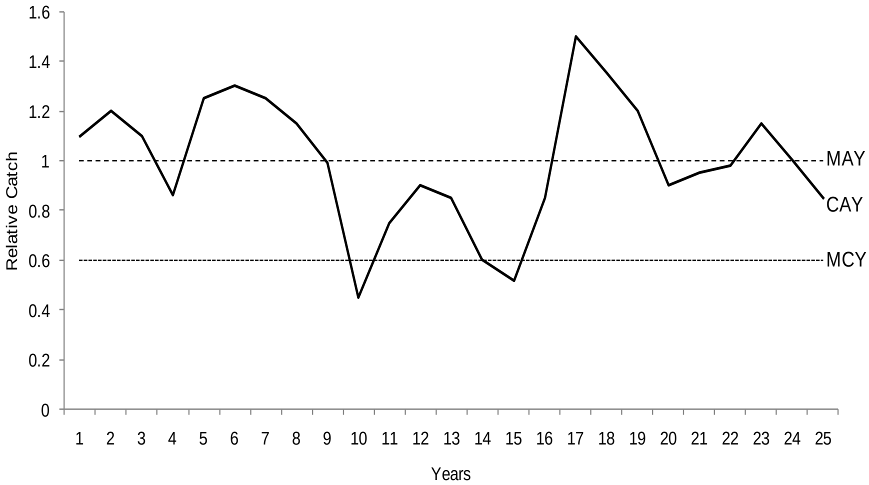

Figure 6. Relationship between ***CAY***, ***MCY*** and ***MAY***.

CAY represents a constant fraction of the fishable biomass which, if estimated and applied correctly, will track the fish population. With a ***CAY*** strategy, the fraction removed remains constant. With an ***MCY*** strategy, the fraction of a population that is removed by fishing increases with decreasing stock size. A constant catch strategy at a level equal to the ***MAY*** would involve a high risk at low stock sizes. ***MCY*** is therefore less than ***MAY*** to ensure that constant catches under this strategy will always be low enough so that the fraction of the population removed does not constitute an unacceptable risk to the future viability of the population. ***MCY*** could be used in a regime where a catch level was to be set for once and for all. With a ***CAY*** strategy the yield would need to change in response to stock sizes.